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# The Humus in Eroded Gray Forest Soils in the Region West of the Urals and Changes Effected by Planting Mixed Grasses

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It is shown that the state of the humus in eroded Gray Forest soils planted to perennial grasses comes close to that in uneroded soils. Restoration of fertility follows the pattern of zonal soil formation.

**Key words:** Eroded Gray Forest soils, effect of planting mixed grasses, region west of Urals

In the northern forest-steppe of the Bashkir Republic, more than 75 percent of the arable land is located on slopes, and this entire area is more or less subject to the forces of erosion. The most active part of the soil is lost in erosion—humus reserves are reduced. The most important soil properties, those which determine fertility, are related, of course, to the quantity and quality of humus in the soil. Eroded soils are different not only in their reduced content of humus but in the altered nature of the humus [3, 8, 13, 15], and for this reason it is very important to optimize the state of the humus in eroded soils. Our studies, which were done in the northern forest-steppe zone of Bashkiria on Gray Forest soils eroded to different degrees, showed that moderately eroded Gray Forest soils contained 2.7 percent humus, severely eroded soils—1.73 percent, and uneroded soils—4.29 percent; that is, the humus content of moderately eroded soils was 35 percent less than that of the uneroded soils, and that of the severely eroded soils was 60 percent less.

Erosion not only reduced the humus content but also strongly affected its quality. As the degree of erosion increased, the content of the humic acids declined while the percent content of fulvic acids and unhydrolyzed residue increased.

Where the humic acids predominated in the humus of the uneroded Gray Forest soils, in the same layer of severely eroded soils, the quantity of humic acids was 27 percent less and the content of fulvic acids was 6 percent higher. Within the humic acids, the content of the mobile fraction, HA-1, was sharply reduced. The content of HA-1 in moderately eroded soil was 29 percent



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Table 1

Humus State Indexes for Gray Forest Soils Eroded to Different Degrees

| Humus reserves in the 0- to 20-cm layer, tonnes/ha | Humus | Degree of humification | $C_{HA}/C_{FA}$, type of humus | Humic acid content, % of total | | | Unhydrolyzed residue, % | $E_{465}^{0.001\%}$ |
|---|---|---|---|---|---|---|---|---|
| | % | | | HA-1 | HA-2 | HA-3 | | |
| | | | | Uneroded soil | | | | |
| 91<br>Low | 4.29<br>Medium | 39.8<br>High | 1.36<br>Fulvate-humate | 41.3<br>Medium | 46.2<br>Medium | 12.5<br>Medium | 30.9<br>Low | 0.158<br>High |
| | | | | Moderately eroded soil | | | | |
| 68<br>Low | 2.76<br>Low | 36.5<br>High | 1.09<br>Fulvate-humate | 26.9<br>Low | 50.8<br>Medium | 22.3<br>High | 36.0<br>Low | 0.114<br>High |
| | | | | Severely eroded soil | | | | |
| 35<br>Very low | 1.73<br>Very low | 29.2<br>Medum | 0.93<br>Fulvate-humate | 16.43<br>Very low | 52.39<br>Medium | 30.8<br>High | 40.1<br>Medium | 0.074<br>High |

less than in uneroded soil, and 70 percent less in the severely eroded soil. At the same time, the content of calcium humates (HA-2) was not significantly reduced in soils eroded to different degrees. The content of fraction HA-3, humic acids bound to clay separates and stable sesquioxides, increased with increasing erosion. In severely eroded Gray Forest Soils, the content of HA-3 was 31 percent higher than in the uneroded soil. As for the fulvic acids, the content of fractions FA-1a and FA-3 increased with increasing erosion while the content of fractions of FA-1 and FA-2 decreased.

A rating scheme for the state of the humus in Gray Forest soils eroded to various degrees, as developed by Orlov and Grishina [14], is given in Table 1. The content of humus in uneroded Gray Forest soils is considered to be moderate, and for this reason, their humus reserves are rated as low. Erosion reduces the humus reserves by more than half.

The degree of humification decreased as the degree of erosion increased. The change in the composition of the humus—a reduction in the percent content of humic acids and an increase in the content of fulvic acids—resulted in a narrowing of the $C_{HA}:C_{FA}$ ratio.

The content of free humic acids declined with increasing degree of erosion from medium to very low. In the Gray Forest soils, most of the humic acids belong to the HA-2 group; both the absolute and the relative contents of this fraction were quite high. It is interesting to note that while the absolute content of the fraction decreased with increasing degree of erosion, the content of calcium humates in the total content of humic acids increased in the severely eroded soils by more than 17 percent. The content of HA-3 fraction increased with the degree of erosion and was characterized as high in the severely eroded soils.

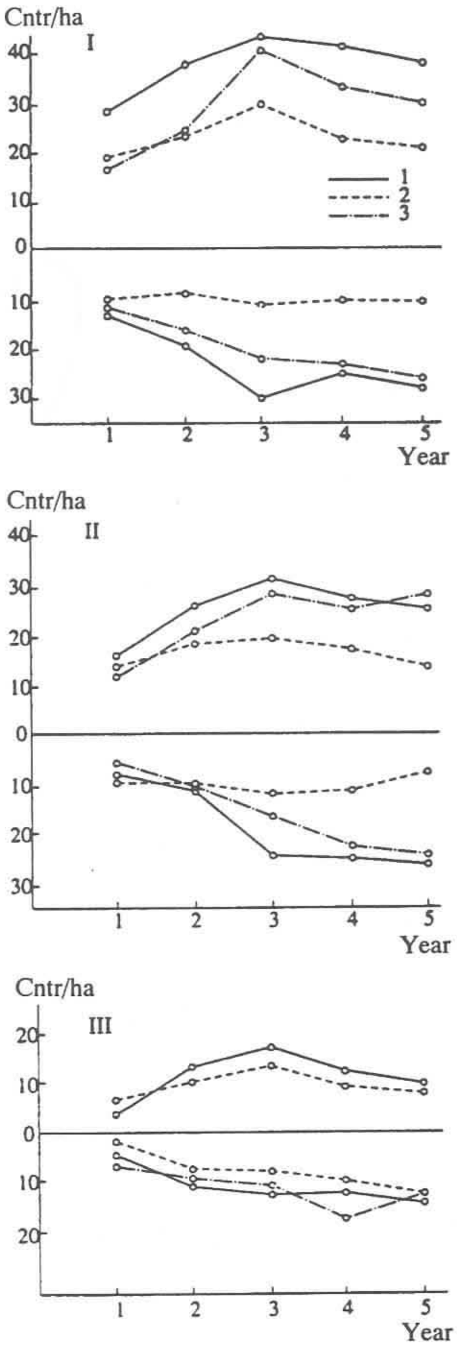
The decrease in the content of humus and the change in its composition were also reflected in the optical density characteristics of the humic acids: the humus became less condensed.

Humus subject to the forces of erosion becomes less active and there is an increase in the relative content of the mobile component of the humus, the part bound to clay particles and stable sesquioxides. This situation supports and raises the content of unhydrolyzed residue in the eroded soils. In uneroded soils, the content of unhydrolyzed residue (30.0 percent) is described as low, but in severely eroded soils (40.1 percent) it is rated as medium.

Thus the condition of the Gray Forest soils is significantly deteriorated by erosion, and it is therefore very important to optimize the humus state in eroded soils.

With a view to accomplishing this task, we undertook a study of the effect of long-term (5-year) growth of legumes (blue hybrid alfalfa), grass (tall fescue), and a legume-grass mixture (red clover, blue hybrid alfalfa, and tall fescue) on the humus state of Gray Forest soils in all stages of erosion.

Perennial grasses stop erosion almost entirely, stabilizing the soil with their thick root systems. Under perennial grasses erosion was cut in half already in the first year, and by the end of the third year it was stopped completely. As the erosion processes are suppressed in a soil under the influence of the perennial grasses, biochemical processes are turned toward restoration of soil




Patterns of variation in the aboveground phytomass (A) (cntrs[1]/ha) and underground phytomass in the 0–50 cm soil layer (B) on slightly eroded (I), moderately eroded (II), and severely eroded (III) Gray Forest soils. Curves: (1) Legume–grass mixture, (2) legumes only, and (3) grass.

[1] One cntr (= centner) = 100 kg.

fertility. The perennial grasses, which develop substantial amounts of plant material above and below the ground, provide a considerable amount of raw material for humus formation in the form of stubble and root residues.

In our experiments, the mass of grass material increased from the first year of growing the grasses to the third year on soils in all stages of erosion. Throughout the life of the plants, the biomass of the legume-grass mixture surpassed the biomass of the grasses planted alone. The greatest yield of plant material in the experiments was produced by the legume-grass mixture in the third year. Among the unmixed crops during the first years, the legumes developed faster and better, but as early as the second year the biomass of the grasses began to surpass the others.

The high productivity and long life of the grasses are conditioned largely on a well-developed root system. Also, of course, replenishment of the humus depends not only on the quantity and quality of the precursor materials but to a considerable extent also on how they reach the soil. For instance, Kostychev [12] has reported previously that organic matter which builds up not within the soil but on the soil surface cannot participate in the accumulation of humus in the soil. When the organic matter is incorporated in the soil, 2–3 times more of its breakdown products ends up in humic substances than when the organic matter builds up on the surface [17].

The growth of the root system of the grasses follows the same pattern as the growth of the aboveground parts of the plants (Figure). The root system gradually enlarges from the first year to the fifth year of growth. The root system mass of the legume-grass mixture increased by 60 percent in five years on slightly eroded soil, by 65 percent on moderately eroded soil, and by 65 percent as well on severely eroded soil. The corresponding figures for pure stands of grass were 52, 58, and 50 percent. The root biomass was maximum in the fifth year of growth for both the legume–grass mixture and the pure stands of grass. The pattern was different for the alfalfa alone. On weakly and moderately eroded soils, the root mass was maximum in the first year of growth, and on severely eroded soils, in the third year.

An important index of root system productivity is the phytomass ratio of tops to roots. This ratio indicates the quantity of dry organic matter in the tops per unit mass of roots [7].

Root productivity depends on a number of factors—plant species, plant age, and the fertility of the soil.

In our experiments, the legume–grass mixture showed the highest root productivity, especially during the first two years. Productivity tapered off gradually in the later years. Root productivity of the alfalfa was highest in the third year, then dropped off gradually. The grass showed the same pattern. Productivity was minimum on the severely eroded soils. The reason for this was that the more the soil properties deviated from optimum, the greater the need of the plant for a thick root system, so that the ratio of tops to roots narrowed. Grasses in their fifth year showed the lowest phytomass ratio of tops to roots regardless of the degree of erosion of the soil (that is, 0.6, where the underground phytomass was more than twice as large as that aboveground).

The quantity and rate of humus accumulation in eroded soils depended on the kind of grasses grown. Humus formation was most rapid where the legume–grass mixture was planted,

and in pure stands five years after planting no significant differences were observed in the humus content between the soil supporting legumes and that under grass.

Humus accumulation was more rapid under alfalfa during the early years, and then the rate of humus formation slowed down significantly. During the first three years, the humus content in moderately and severely eroded soils increased by an average of 0.52 percent, but in subsequent years, the rate of accumulation was reduced by a factor of three.

The opposite pattern was observed where grasses were planted. During the early years, the rates of humus formation were quite low—lower than under alfalfa by a factor of 3 in moderately eroded soils, and by a factor of 3.9 in severely eroded soils. The rate of humus accumulation speeded up as the plantings aged.

There are several reasons for this pattern. First, as has already been pointed out, the accumulation of organic residues is slower under grasses during their early years because of their slow growth on eroded soils. Second, as has been reported in numerous studies [1, 2, 10, 11], alfalfa residues break down and become humus considerably faster than grass residues. Our data also confirm this. About 80 percent of the alfalfa residues and about 50 percent of the grass residues had decayed after a year.

The biological activity of the soil, moreover, was higher under the legumes than under the grass, a fact that also influences the speed of humification.

Humus accumulation under the legume-grass mixture was more uniform.

It must be noted that the rate of humus accumulation was higher, the greater the degree of erosion of the soil. In slightly eroded soils, the rate of humus enrichment was quite slow even though organic matter was being added continuously, while in severely eroded soils the rate was considerably higher. In slightly eroded soils under the legume-grass mixture the humus content increased by 0.46 percent in 5 years, while in moderately eroded soils the increase was 0.91 percent, and in severely eroded soils the increase was 1.12 or 2.3 times.

Here we see that, over the years, the forces of erosion have disrupted the established equilibrium of biochemical processes in the soil, and the soil system, under conditions that are more or less favorable, tries, as it were, to restore the previous situation which corresponded to particular zonal conditions of soil formation. The more a soil deviates from its analogues which have not been subject to the action of erosion, the greater its potential "need" to restore the level of fertility which is natural for that particular soil group.

Perennial grasses, by promoting the accumulation of humus in eroded soils, alter the group and fractional composition of the humus. Changes in the group composition of the humus in Gray Forest soils depend largely on the type of grass being grown. All kinds of grasses favor the accumulation primarily of humic acids in the humus (Table 2). Where the legume-grass mixture and the pure stands of alfalfa were grown humic acids accumulated more rapidly than under grasses alone. The content of humic acids in soils where the legume–grass mixture was growing increased from 33.4 to 38.2 percent in 5 years, that is, by 12 percent, whereas the increase was only 8 per-

Table 2

Content and Composition of the Humus of Gray Forest Soils after Five Years of Growing Pasture Grasses

| Grasses | Humus, % | Humic acids | | | | Fulvic acids | | | | | Unhydro-lyzed residue | $C_{HA}:C_{FA}$ | $E_{465}^{0.001\%}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | HA-1 | HA-2 | HA-3 | Σ | FA-1a | FA-1 | FA-2 | FA-3 | Σ | | | |
| Slightly eroded soil | | | | | | | | | | | | | |
| Control | 4.12 | 12.1 | 17.8 | 7.0 | 36.9 | 6.3 | 10.3 | 11.0 | 3.1 | 30.7 | 32.4 | 1.14 | 0.124 |
| Legume–grass | 4.58 | 12.3 | 18.2 | 7.9 | 38.4 | 3.5 | 11.7 | 11.6 | 2.5 | 29.3 | 32.3 | 1.31 | 0.154 |
| Legume | 4.50 | 11.9 | 18.3 | 8.0 | 38.2 | 4.7 | 11.6 | 11.5 | 2.0 | 29.5 | 32.3 | 1.29 | 0.150 |
| Grass | 4.55 | 12.0 | 17.9 | 7.5 | 37.4 | 4.9 | 12.0 | 10.9 | 2.0 | 29.8 | 32.8 | 1.26 | 0.149 |
| Moderately eroded soil | | | | | | | | | | | | | |
| Control | 2.76 | 9.0 | 16.0 | 7.4 | 32.4 | 6.5 | 9.8 | 10.9 | 3.4 | 30.6 | 37.0 | 1.05 | 0.114 |
| Legume–grass | 3.59 | 12.9 | 17.9 | 7.4 | 38.2 | 5.6 | 9.2 | 11.2 | 3.3 | 29.3 | 32.5 | 1.30 | 0.128 |
| Legume | 3.37 | 11.0 | 18.1 | 7.3 | 36.4 | 4.3 | 8.8 | 11.2 | 4.2 | 28.5 | 35.3 | 1.27 | 0.130 |
| Grass | 3.39 | 12.5 | 16.7 | 7.0 | 36.2 | 5.9 | 10.4 | 9.3 | 3.8 | 29.4 | 35.0 | 1.23 | 0.121 |
| Severely eroded soil | | | | | | | | | | | | | |
| Control | 1.73 | 4.8 | 15.3 | 9.0 | 29.2 | 7.6 | 9.0 | 10.4 | 4.0 | 31.0 | 40.1 | 0.93 | 0.074 |
| Legume–grass | 2.81 | 7.8 | 18.0 | 9.1 | 34.9 | 6.5 | 9.1 | 10.4 | 3.1 | 29.1 | 36.0 | 1.20 | 0.124 |
| Legume | 2.43 | 6.6 | 18.3 | 9.2 | 34.1 | 6.0 | 8.5 | 10.7 | 4.7 | 29.9 | 36.0 | 1.14 | 0.124 |
| Grass | 2.37 | 7.1 | 16.4 | 9.0 | 32.5 | 7.5 | 11.6 | 10.4 | 4.2 | 31.7 | 35.8 | 1.02 | 0.119 |

cent under alfalfa and 6 percent under grass. In the severely eroded soils, the humic acid contents increased by 17, 15, and 11 percent, respectively.

In general, the $C_{HA}:C_{FA}$ ratio was higher under all kinds of grasses, but this ratio was not as wide under the pure stands of grass because of the elevated content of fulvic acids. The humus of soils in all states of erosion planted to grass alone tended to have a higher percentage of fulvic acids, especially during the early years of growth.

The amount of unhydrolyzed residue was reduced under all kinds of grasses. It must be noted that in the slightly eroded soils no reliable changes were observed in the group composition.

Changes were also observed in the fractional composition of both humic and fulvic acids in the Gray Forest soils.

According to a number of investigators [9, 18], those humus fractions which are richest in nitrogen and whose macromolecules are relatively simple in structure are especially valuable as a source of ready reserves of soil fertility. Of particular interest in this respect are the mobile and unstable humic acids of fraction HA-1. In our experiments, the content of this fraction increased under perennial grasses in eroded soils. Where the alfalfa-grass mixture was grown, the plow-layer content of HA-1 increased by 30 percent in moderately eroded soil, and by 38 percent in severely eroded soil. Where pure stands of grass were planted, this fraction accumulated faster. After 5 years of growing grass on moderately eroded soils, the content of HA-1 in the soil increased by 28 percent, by 32 percent in severely eroded soils; analogous figures for soils on which legumes grew were 18 and 27 percent, respectively. During the early years, the accumulation was faster under the alfalfa, but then the rate slowed. The opposite pattern appeared in the case of pure stands of grass; that is, the rate of increase accelerated in the third year. Where the HA-1 content increased, an average of 10 percent from the first to the third year, the rate of increase was 25 percent from the third to the fifth year.

Two-factor analysis of variance was used to determine the effect of degree of erosion and grasses in different years on the content and composition of the humus. The results showed that the principal factor governing the accumulation of HA-1 was the grasses. In the case of the severely eroded soils, the two factors—grasses and growth years—were of almost equal significance.

The content of fraction HA-2 also increased under perennial grasses. This increase was most apparent in soil where pure stands of alfalfa were grown. The increase associated with alfalfa on moderately eroded soils was 12 percent; on severely eroded soils, 16 percent; with legume–grass mixtures, 11 and 15 percent, respectively; and with pure stands of grass, 4 and 7 percent.

The content of the least mobile fraction of humic acids, HA-3, remained practically unchanged, but, as has been already mentioned, as the erosion processes intensified the content of this fraction increased. From our data, we note only a poorly defined tendency toward a reduced percentage of this fraction within the humic acids. The absolute content of HA-3, however, remained unchanged.

Optical density readings were used to describe the nature of the humic acids in eroded Gray Forest soils and the effect of cultivation on the composition of the acids.

Erosion processes affect the extinction coefficients of humic substances. As erosion intensifies, optical density usually diminishes. There are several reasons for this. First, as erosion progresses the less humified lower horizons are exposed, where the optical density of the humic substance is less. Second, biological activity in eroded soils is low and there is practically no "ripening" of the humic acids. Also, as long as surface runoff and soil wash continue unchecked, the most soluble "young" humic acids are washed out of the soil and the supply of humic acid building blocks is reduced.

As has already been mentioned, planting perennial grasses on eroded Gray Forest soils stops the erosion and promotes the accumulation of humic acids. The optical density of the humic acids in eroded Gray Forest soils after grasses have been growing five years is higher than in similar eroded Gray Forest soils without the grasses. The color index of the humic acids ($E_{465}/E_{650}$) in moderately eroded soils changes from 3.55 to 3.17, and in severely eroded soils from 4.83 to 3.75.

The average values of the extinction coefficients associated with different perennial grasses after five years of growth were practically the same; that is, no clear relationship was observed between optical density and plant species. A difference was detected only in the early years of growth. The extinction coefficients for humic acids from soil under pure stands of grass were significantly lower than for those from soil under the legume–grass mixture and the pure stands of alfalfa. This evidently occurs because the HA-1 fraction accumulates faster where grasses are grown alone, and this fraction has a lower optical density than the HA-2 and HA-3 fractions. It is interesting to note that the color indexes were practically the same for all the plantings.

The optical density values of humic acids in moderately eroded Gray Forest soils after five years under grass were approximately equal to the extinction coefficients of the humic acids in virgin Gray Forest soils, while the optical density of the severely eroded soils approached that of slightly eroded soils. The nature of the variation in humic acid extinction coefficients across the soil profile remained the same; that is, they declined with depth.

Higher optical density, of course, is characteristic of the more mature humic acids and those which are thermodynamically more stable (according to D.S. Orlov's theory of humification). The content of the eroded Gray Forest soils under perennial grasses favors the formation of the more stable and optically denser humic acids.

Changes were also observed in the fractional composition of the fulvic acids. Of greatest interest here were the FA-1a and FA-1 fractions, which are readily mineralized and are involved in the nutrition of microorganisms and plants.

The content of the most mobile fractions declined where the legume–grass mixture and the pure stands of alfalfa were planted. The biological activity under the grasses was somewhat less than under the mixture containing legumes, and for this reason, the content of the FA-1 and FA-1a fractions under the grasses was higher. This situation was seen most clearly in the severely eroded soils.

Fractions FA-2 and FA-3 were most resistant to the influence of external conditions and microorganisms. The content of fraction FA-2 changed in the same way as that of the HA-2 fraction. Practically no differences were observed between changes in the content of FA-3 and HA-3.

The composition and properties of humus as well as its distribution across the soil profile are closely related to the direction and intensity of the soil-formation process associated with particular natural conditions [10, 16]. In the opinion of most investigators, the composition of the humus provides an adequate basis for making decisions about the soil's organic matter and its relationship to the initial conditions of pedogenesis [4–6, 19].

The mature humus in the eroded Gray Forest soils was fulvate-humate in nature; fractions associated with sesquioxides and calcium predominated. Most of the humic acids were concentrated in the upper layer of the soil. The soluble humus fractions were clearly more abundant than the insoluble residue.

The indexes describing the humus state of the eroded Gray Forest soils under perennial grasses were close to those of the uneroded soils. The ratio of humic acids to fulvic acids in the soils under perennial grasses, especially under the grass–legume mixture, was almost the same as the ratio typical of the Gray Forest soils. Humification of the soil organic matter was sharply higher, and there was a much greater content of tightly bound humic acids than in their uneroded analogues. The content of the HA-2 fraction reached the level typical for the Gray Forest soils.

It may be concluded, therefore, that when perennial grasses are planted on soils damaged by erosion, restoration of fertility will proceed in a manner typical of the zonal soil formation process. When eroded Gray Forest soils of low productivity are reclaimed by planting grasses, it is possible to restore the optimum humus conditions characteristic of the uneroded zonal soils, which will assure maximum crop yield.

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